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ABSTRACT

The purpose of this study was to examine the relationship between science teacher knowledge and changes in student content knowledge after students experienced microcomputer-based laboratory (MBL) instruction about heat energy and temperature. Investigation of teacher knowledge included evaluation of content knowledge and pedagogical content knowledge. The teachers' MBL instruction was described in terms of the type and number of MBL activities conducted. The study sample consisted of experienced eighth grade teachers (n=6) and their students (n=22). Interview transcripts serve as the sole data source for the teachers and students in this study. Participants' knowledge was identified using prepositional analysis. The strongest evidence of a relationship between teacher pedagogical content knowledge and student content knowledge was between changes in student knowledge and the amount of a particular type of instruction. The relationship existed only with those activities that emphasized the distinction between heat energy and temperature. Nine tables present the data. (LZ)

THE RELATIONSHIP BETWEEN TEACHER CONTENT AND PEDAGOGICAL CONTENT KNOWLEDGE AND STUDENT CONTENT KNOWLEDGE OF HEAT ENERGY AND TEMPERATURE

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Purpose

The purpose of this study was to examine the relationship between science teacher knowledge and changes in student content knowledge after students experienced microcomputer-based laboratory (MBL) instruction about heat energy and temperature. Investigation of teacher knowledge included evaluation of content knowledge and pedagogical content knowledge. The teachers' MBL instruction was described in terms of the type and number of MBL activities conducted, especially with regard to the activities that emphasized the distinction between heat energy and temperature.

Theoretical Background

Recent research indicates that teacher content knowledge influences "both what teachers teach and how they teach it." (Grossman, Wilson, & Shulman, 1989, p. 26) Specifically, studies of science teachers have shown that the *amount* and *kind* of content knowledge influences instruction (e.g. Carlsen, 1988; Hashweh, 1987; Sanders, 1990; Smith & Neale, 1989). Considering the relationship between teacher content knowledge and teaching, findings from previous research investigating the relationship between teacher content knowledge and student achievement are surprising: studies reported little or no statistical relationship between those variables. The variables used to represent teacher knowledge are considered the major reason for that counter-intuitive result: general, rather than specific teacher knowledge was assessed.[1]

Notwithstanding that explanation, the lack of a relationship may also have been the result of a lack of attention to other important teacher knowledge. For example, although content knowledge influences teaching, the teaching actions of equally knowledgeable teachers can differ considerably (Bellamy, 1990). That finding can be explained in terms of another type of teacher knowledge: pedagogical content knowledge. This knowledge consists of what teachers know about how to teach specific subject matter, and it has been shown to influence the content and process of instruction (e.g. Grossman, 1988, Shulman & Grossman, 1988). Specifically, studies of science teachers have shown that the *amount* and *kind* of pedagogical content knowledge also influences instruction (Bellamy, 1990; Borko, Bellamy, Sanders, 1990; Sanders, 1990; Smith & Neale, 1989).

These results suggest that there is a need to revisit the question of the relationship between teacher and student knowledge, using more appropriate representations of teacher knowledge. Shulman and colleagues' (1986, 1987; Shulman & Grossman, 1988; Wilson, Shulman, & Richert, 1989) description of the logical components of the knowledge base of teaching, provides a useful conceptual framework for defining teacher knowledge.[2] The previously cited research on teacher content and pedagogical content

[1] Variables used to represent teacher content knowledge included: number of college science courses, college GPA, number of academic credits. For a list of the variables used in a large portion of previous studies in science education concerning the relationship between teacher characteristics and student outcomes, see Druva & Anderson (1983).

[2] See also, Wilson, Shulman, & Richert, 1987).

knowledge lends support to examining those types of knowledge in particular, with respect to the investigation of the relationship between teacher and student knowledge.

Research Design

This study was an outgrowth of a larger project entitled the "University of Maryland Middle School Probeware Project"[3] (UMMPP). That project had a combined teacher enhancement and research on teaching focus (Layman & Krajcik, 1987). A primary component of the UMMPP teacher enhancement effort consisted of two intensive, three-week summer workshops held in consecutive years. The workshops focused on the use of MBL activities for instruction about heat energy and temperature. The teachers used those activities as the basis of their instruction about heat energy and temperature during the school year.

This study utilized teacher and student data from the second year of UMMPP to investigate the relationship between teacher and student knowledge. The study sample consisted of experienced eighth grade teachers and their students. The teacher sample in this study (n=6) consisted of a sub-group of a randomly-selected group of teachers chosen at the beginning of UMMPP to participate in the research component. The sub-group represented those teachers from the randomly-selected group who had participated in two years of UMMPP. That time span of involvement included attendance at introductory and advanced workshops, and conducting instruction about heat energy and temperature during each year of the two-year project. The student sample (n=22) consisted of one randomly-selected student from four of each teacher's classes during the second year of UMMPP.

Data Sources

Interview transcripts serve as the sole data source for the teachers and students in this study. The interviews were semi-structured; that is, they each contained the same basic set of questions but interviewers were free to pursue unique lines of inquiry when needed to establish a participant's knowledge about the concepts of interest. Teacher and student interview protocols (see Figure 2) contained similar questions designed to elicit general information about the concepts of heat energy and temperature and the relationship between those concepts, as well as specific information about the influence of volume and temperature on the transfer of heat energy. The protocol for the teacher interview contained additional questions about teacher pedagogical content knowledge. Specifically, questions were designed to elicit teacher knowledge of student understanding and alternative conceptions, and knowledge of topic-specific pedagogical strategies for teaching about heat energy and temperature. Finally, the teachers were also required to describe the MBL activities they used for teaching about heat energy and temperature.

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The interviews consisted of a series of tasks presented to participants. For content knowledge there were four tasks: two open-ended tasks and two problem-solving tasks. Figure 1 shows the common elements of the tasks presented to both teachers and students. For pedagogical content knowledge there were four tasks paralleling the content knowledge tasks.

Interviews were conducted with participants on an individual basis. Props were used to illustrate hypothetical situations presented to the participants. They included diagrams, a thermometer, graduated beakers of water, and labels to distinguish the beakers of water (Beaker A and Beaker B) and to provide information about the hypothetical starting temperatures of the water in each beaker.

Data Analysis

Two interviews conducted with each participant were analyzed for this study, one at the beginning and one at the end of the school year. Interviews with teachers were conducted during their planning period or after school. Participants' knowledge was identified using propositional analysis. The first step in analyzing the transcripts was to reduce the data from each interview to a set of statements relevant to each participant's knowledge of the concepts of interest. For content knowledge, participants' statements related temperature, heat energy, or the relationship between heat energy and temperature were compiled from each interview. For pedagogical content knowledge, teachers' statements about what the students were likely to know, what students might find difficult, what was important for students to know, and how they would help students improve their knowledge were compiled from each interview. Different procedures were employed to analyze the participants' content knowledge and the teachers' pedagogical content knowledge. Those procedures are discussed below.

Content Knowledge

Participants' content knowledge was analyzed separately for the following areas: a) temperature, b) heat energy, and c) the relationship between heat energy and temperature. In each case, frameworks were established for analyzing the participants' knowledge. Pre-established frameworks were used as well as frameworks developed from patterns in the data.

Knowledge of temperature and heat energy. Participants' knowledge of temperature and knowledge of heat energy were determined using pre-established frameworks consisting of the components of those concepts. The components were partly selected from physics and chemistry textbooks and partly on the basis of their match with content knowledge addressed in the UMMPP workshops. Figure 2 shows the components of each concept, as well as examples of the kind of statements that constituted evidence of particular knowledge. For example, a statement that "temperatures are being recorded by a thermometer" provides evidence of knowledge that temperature is measured with a thermometer.

Aside from correct or incorrect knowledge of the components of heat energy and temperature, alternative conceptions of these concepts were also of concern. Alternative conceptions, sometimes

called misconceptions, are knowledge held by learners that differs from accepted scientific knowledge (Wandersee, 1985). Despite being incompatible with scientific knowledge, alternative conceptions have special distinction as broader in scope than factual knowledge (e.g., Driver & Erickson, 1983; Osborne & Wittrock, 1983). Some researchers have used the term "alternative conceptual frameworks" rather than alternative conceptions to indicate that the conceptions are part of a larger conceptual structure containing ideas that are incompatible with correct scientific knowledge (Driver & Erickson, 1983). The alternative conceptions about heat energy and temperature that were identified in this study are shown in Figure 2, along with examples of statements that constituted evidence of a particular conception.

The data were analyzed for evidence of knowledge with respect to each component of heat energy and temperature. Inter-rater reliability was assessed at the level of agreement on judgments of knowledge of each component of a concept, and the alternative conceptions. With regard to the concept of temperature, the inter-rater agreement was 88%; with regard to the concept of heat energy, the agreement was 90%; and with regard to the alternative conceptions, the agreement was 100%. Disagreements were settled by mutual consent.

Knowledge of the relationship between heat energy and temperature: The relationship between heat energy and temperature. Participants' knowledge of the relationship between heat energy and temperature was examined from two perspectives: (a) the relationship between the concepts and (b) application of the relationship in problem-solving (Beaker Task). Participants' knowledge of the relationship was analyzed using categories established from patterns that emerged from the data rather than a pre-determined framework. Taxonomic analysis was used to develop broad categories and to further define the categories. The result was a list of specific propositions (Master List) based upon patterns in the data which represented the range of knowledge exhibited about the relationship between heat energy and temperature. Figure 3 shows the Master List of propositions.[4] The broad categories are marked with roman numerals and shown in all capital letters in the figure; the specific propositions are preceded by numbers.

The propositions on the Master List vary in terms of whether or not they express correct knowledge of the relationship between heat energy and temperature. In Figure 3, the correct propositions are highlighted in bold and the numbers of the correct propositions are followed by an asterisk. Ten propositions express correct knowledge: 2, 9, 16, 18–20, 26, and 31 – 33. Some propositions are correct only under certain circumstances. Qualifying information required to match those propositions is italicized in brackets following the proposition.[5] For example, proposition 9 is only

[4] The phrases and language of the propositions on the Master List are similar to the that of the students and the teachers. The phrases are more general than was common in a participant's statement; participants typically made several related statements that corresponded to one proposition on the Master List.

[5] The fifth category contains statements with volume as one variable influencing heat energy. The correct variable is mass, not volume; however, because the propositions reflect the language of the participants, and participants

true in very specific circumstances such as a single substance which is not going through a change of state; proposition 19 is true in the circumstances of different volumes of the same substance cooling to room temperature from the same starting temperature. For participants to be judged as having knowledge matching propositions with qualifiers, they need to provide information matching the qualifying information as well as the proposition.

To underscore the significance of some of the differences in the categories of propositions, Figure 3 requires additional commentary. One important difference occurs between categories three and four. Some of the propositions in third category offer contradictory views about the relationship between heat energy and temperature to those in the fourth category. For example, the proposition in category three that temperature indicates the amount of heat energy implies that heat energy *causes* temperature. The propositions in category four indicate that heat energy causes a change in temperature, but *not* that it is the *cause* of temperature. A participant would *not* be expected to exhibit propositions in both categories.

Another important difference occurs in categories six, seven, and eight. The categories represent substantially different conceptualizations of heat energy and temperature. The key idea shared by the propositions in each category is indicated by the final term in the category title. For example, in the eighth category, the key idea is energy transfer: all the propositions in this category invoke the idea of transfer of energy with temperature being an indicator of the transfer. The sixth category is unique in that, with the exception of the first proposition in that category (proposition 21), the propositions do not include information about temperature. The inclusion of this category for representing knowledge about the relationship between heat energy and temperature is warranted because temperature, not heat energy, is defined in terms of motion. In other words, although the propositions in this category do not explicitly address the relationship between heat energy and temperature, they implicitly include temperature because they contain the same conceptualization used for thinking about temperature (i.e., molecular motion). Thus this perspective is important to examine because it suggests the distinction between heat energy and temperature is blurred.

Inter-rater reliability of the results of this analysis was at the level of agreement on judgments of which propositions were exhibited by each participant. Inter-rater agreement was 83%. Disagreements were settled by mutual consent.

Knowledge of the relationship between heat energy and temperature: Beaker Task. The second analysis of knowledge of the relationship between heat energy and temperature employed data from only the Beaker Task. Two aspects of participants' responses were evaluated: (a) their answer choice in each situation (which beaker of water would lose more heat energy), and (b) their reason for choosing an answer. Participants' reasoning could differ with regard to whether one or both of the

typically described situations involving water, identification of volume rather than mass was considered an acceptable alternative, and qualifying information was not included in bracketed information.

variables of temperature and volume of water were considered. Beaker A was the correct answer choice in all situations, and arriving at that answer choice in all situations required quantitative reasoning using both variables. In one situation, however, participants could correctly consider both variables but arrive at the wrong answer if they reasoned qualitatively (e.g., 20 mL of water starting at 90°C would lose about the same amount of heat energy from cooling as 80 mL of water starting at 45°C because the smaller volume would be offset by the higher temperature). Hence, analysis of participants' reasoning with regard to whether or not both variables were considered provided different information from analysis of the correctness of their answer choice.

Assessment of the participants' answer choices was carried out by calculating the percentage of correct answer choices for each participant in each interview. Increases in the percentage of correct responses across the interviews were considered evidence of the presence of more correct knowledge than previously held. Analysis of participants' reasoning was carried out only with regard to the two task situations in which both the temperature and volume variables differed[6]. Reliability of the second analysis was conducted on a sub-sample of the data with an experienced graduate research assistant knowledgeable about heat energy and temperature. The sub-sample -- one teacher and six students -- was randomly selected and represented 17% of the teacher data and 27% of the student data. Reliability was at the level of agreement on judgments of whether both variables were considered in reasoning about the task. The agreement was 96%. Disagreements were settled by mutual consent.

Pedagogical Content Knowledge

Investigation of participants' pedagogical content knowledge was guided by definitions of the components of that knowledge most recently supplied by Shulman and his colleagues (Shulman & Grossman, 1988). Figure 4 describes these components. The teacher interview elicited information about teachers' knowledge related to three of the components: alternative frameworks, student understanding and misconceptions, and pedagogical strategies. In the case of the student understanding and misconceptions (hereafter called student understanding) and pedagogical strategies components, there were specific questions in the interview protocol to elicit the teachers' knowledge. In the case of the alternative frameworks component (hereafter called content framework), there were *not* specific questions in the interview protocol to elicit information about the teachers' knowledge; however, some of the questions produced information from which knowledge related to this framework could be inferred.

[6] Although all the task situations required attention to both variables, participants did not always explicitly describe their attention to both variables in the task situations in which temperatures were equal. Probing by the interviewer sometimes revealed whether a participant made explicit reference to both variables in those situations, but such probing was not consistent across all the interviews. Hence, to arrive at an assessment of whether participants considered both variables, without the confounding factor of the interviewer, it was decided to only make judgements in the situations obviously requiring attention to both variables.

The aspects of the student understanding component relevant to this study were: (a) knowledge of common incorrect knowledge and reasoning students employ in problem-solving tasks about the relationship between heat energy and temperature, and (b) knowledge of the concepts and skills that prove difficult for students to understand and acquire. The aspect of the pedagogical strategies component relevant to this study was the repertoire of representations useful in teaching about the relationship between heat energy and temperature. Finally, the aspect of the content framework component relevant to this study was knowledge of what's important for students to know and understand about the relationship between heat energy and temperature.

Student understanding. For the student understanding component of pedagogical content knowledge, data from the teachers were examined with respect to pre-determined categories for the knowledge. The pre-determined categories were partly from previous research and partly from analyses of other data from the UMMPP. Previous research suggested assessing teachers' knowledge that students often do not distinguish between heat energy and temperature. Previous analyses of similar data from the UMMPP suggested assessing knowledge of the probability that students would select one of the two possible incorrect responses in the Beaker Task problem-solving situation. One incorrect response, that both volumes lose the same amount of heat energy, is often explained by students as the correct answer because both volumes start and end at the same temperature. The other incorrect response, that the smaller volume loses more heat energy, is explained by students as the correct response because more heat energy is lost by the volume which cools more quickly, and that is the smaller volume. Teacher knowledge of common explanations for choosing the incorrect responses was also assessed.

Inter-rater reliability of the analysis for the student understanding component of pedagogical content knowledge was at the level of agreement on judgements of knowledge exhibited with respect to each pre-determined category. Inter-rater agreement was 100%.

Topic-specific pedagogical strategies. The categories used to judge teachers' knowledge of pedagogical strategies were determined partly by the types of teaching strategies possible in classroom science instruction (e.g., laboratory activity, discussion, reading from a textbook, demonstration) and partly by patterns that emerged from the data. Teachers provided information corresponding to three categories of strategies: laboratory activities, textbook readings, and discussion. Nine categories for distinguishing the laboratory activities described by teachers were developed based upon differences in the variables designated as the dependent and independent variables, or the controlled variables. For example, an activity in which students measure the time it takes for two different volumes of water at the same starting temperature (e.g., 50°C) to cool to room temperature (e.g., 25°C), has the following basic elements: (a) time is the dependent variable, (b) temperature is the controlled variable, and (c)

volume is the independent variable. A similar activity in which students calculate the amount of heat energy lost in cooling to room temperature for two different volumes of water at the same starting temperature, has the following basic elements: (a) heat energy is the dependent variable, (b) temperature is the controlled variable, and (c) volume is the independent variable.

Figure 5 shows the list of categories for the laboratory activities, and examples are provided of the kind of activity that would fit each category. The categories are listed in order to facilitate noting the differences among them. For example, the first five categories have in common that volume was an independent variable because they all designate that different volumes are involved. Of those, the first and second categories are different from the other three because the temperature is controlled or maintained at the same value. Those activities differ because in the first one the change in temperature is the dependent variable and in the second one the amount of heat energy is the dependent variable. The third, fourth, and fifth categories also differ in terms of the dependent variable present, and in addition, the fifth category is different because the amount of heat energy is controlled in addition to the amount of temperature change. The remaining categories are distinguished in a similar fashion.

The categories of laboratory activities were also marked to designate whether or not they emphasize the distinction between heat energy and temperature. Categories that emphasize the distinction include one of the following elements: (a) the amount of heat energy changes but temperature does not, e.g., in a change of phase; (b) a change in heat energy results in different changes in temperature, e.g., adding the same amount of heat energy to different masses of the same substance or the same masses of different substances; and (c) using the value of temperature and other variables to calculate the amount of heat energy transferred, e.g., comparing heat energy transferred to the environment when two volumes starting at the same temperature above room temperature cool to room temperature. Seven of the nine activities contain elements emphasizing the distinction between heat energy and temperature, and they are shown in italicized type.

Inter-rater reliability of the analysis for the pedagogical strategies component of pedagogical content knowledge was at the level of agreement on judgements of the strategies that were described by the teachers. Inter-rater agreement was 83%, and disagreements were settled by mutual consent.

Content framework. The categories used to classify teachers' knowledge with regard to the content framework component were determined partly by the levels at which the concepts can be addressed (macroscopic or microscopic) and partly by patterns that emerged from the data. Figure 6 shows the resulting scheme for classifying teachers' conceptual frameworks. Included in the figure is information about the correctness of the representation of the concepts contained in each framework.

Inter-rater reliability of the analysis for the content framework component of pedagogical content knowledge was at the level of agreement on judgements of which frameworks were exhibited by the teachers. Inter-rater agreement was 87%, and disagreements were settled by mutual consent.

Teaching Activities

The teachers mainly drew upon curriculum materials developed during UMMPP summer workshops for their instruction about the concepts of heat energy and temperature. A list of the activities developed during and in conjunction with the workshops, as well as activities included in the teachers' curricula, was compiled (see Table 9). Each teacher was asked to indicate which of the activities on the list were utilized as a part of his or her instruction in heat energy and temperature[7]. For comparative purposes, the total number of activities from this list was tabulated for each teacher. In addition, using the criteria utilized in relation to the pedagogical strategies analysis, the number of activities emphasizing the distinction between heat energy and temperature was tabulated for each teacher.

It was hypothesized that there would be a relationship between teacher and student knowledge, for both teacher content and pedagogical content knowledge. In addition, it was hypothesized that there would be a relationship between student content knowledge and the number of MBL activities conducted by the teachers.

Results and Discussion

The Relationship Between Teacher and Student Content Knowledge

Temperature

Table 1 shows the results from the analysis of teachers' and students' knowledge of temperature. There are no obvious patterns between teacher and student knowledge for the components of temperature due to the lack of variation in the teacher and the student data. With regard to the alternative conception, however, there are three patterns in the data, and one pattern substantially supports a relationship between the content knowledge of the teachers and their students.

One pattern is that neither Mr. Roberts nor his students exhibited knowledge of the alternative conception. By itself, that pattern could be taken as evidence of a relationship between teacher and student content knowledge; however, there were two other teachers who also did not exhibit the alternative conception, and they each had students who exhibited it. Thus, the

[7] Typically, this information was gathered at some point in the spring interview for each teacher. For Ms. Carlson and Ms. Mason, however, that information was not collected during the interview. In those cases, information about the teachers' instruction was collected during the following school year which was over a year after some of the instruction had been delivered. Nevertheless, the teachers seemed quite certain of the record they provided, and there was no evidence to suggest that was not the case.

fact that a teacher did not exhibit an alternative conception did not assure that his or her students would not.

A second pattern was that Ms. Lowry's students showed the most change from presence to absence of the alternative conception, and she did not exhibit the alternative conception in contrast to other teachers. By itself, this pattern could be evidence of a relationship between teacher and student content knowledge; however, a similar relationship was not found for the other teacher (Ms. Carlson) who did not exhibit the alternative conception but who had students who did. Thus, as with the pattern in the Roberts group, this pattern does not support a general relationship between teacher and student content knowledge.

A third pattern involves the students who exhibited knowledge of the alternative conception in the spring but *not* in the fall interview. Students of three teachers fit this categorization: Baxter's, Gentry's, and Mason's students. The pattern is that those teachers were the only teachers to exhibit the alternative conception at some time in the year. The teachers who did *not* exhibit the alternative conception had students who remained the same or improved with respect to the alternative conception in the spring interview. This pattern is evidence of a relationship between teacher and student content knowledge: teachers with the alternative conception that temperature is a measure of heat energy are substantially more likely to have students who develop the conception as a result of instruction than those teachers who do not possess the alternative conception.

Heat Energy

Table 2 shows the results from the analysis of teachers' and students' knowledge of heat energy. The lack of a match between the components for which the teachers' and the students' knowledge varied, reduced the possibility of finding relationships between teacher and student content knowledge. Nevertheless, there are several patterns in the student data that warrant examination for evidence of a relationship between teacher and student knowledge. One pattern is found in the data of the first component of heat energy: Ms. Baxter's students exhibited the greatest decrease in knowledge in comparison to the other student groups. Ms. Baxter's knowledge of this component was not less than the other teachers', so a relationship between knowledge does not explain the pattern. On the other hand, Ms. Baxter was one of the teachers who exhibited an alternative conception about heat energy and that result may be related to the performance of her students.

The other patterns in the data are found in relation to the fourth component of heat energy shown in Table 2: heat energy is an extensive variable. One pattern is that the Baxter and Mason groups included the only students (Brad and Carynne) who exhibited correct knowledge of this component in the fall but not the spring interview. The only knowledge that Ms. Baxter and Ms. Mason had in common that was not exhibited by other teachers was the alternative

conception that temperature measures heat energy. This commonality may indicate the relationship that teachers who exhibited this alternative conception were more likely to have students who exhibited less correct knowledge of the extensivity of heat energy after instruction than before. This relationship makes sense in that defining temperature as a measure of heat energy contradicts knowledge of the component. Furthermore, another pattern in the data may be confirming evidence of the relationship: Ms. Carlson's and Ms. Lowry's students were the only ones who did not show a decrease in knowledge of the extensive property of heat energy, and neither of those teachers exhibited knowledge matching the alternative conception. In this case, the fact that the teachers did *not* exhibit the alternative concept meant their students were *not* limited in retaining or developing correct knowledge of the component.

On the other hand, the strength of this pattern as evidence of a relationship may be in question because the data are somewhat misleading: knowledge reported as inaccurate (ia) in the table could mean that mass was ignored as a variable, or that it was included but not used correctly. For example, students could correctly indicate that mass influenced the amount of heat transferred but state incorrectly that a *smaller* mass (of the same substance) would lose more heat energy than a larger mass that experienced the same change in temperature. Consequently, the "ia" judgement had more than one meaning, and conclusions related to patterns just comparing *completely* correct knowledge (√) with the other categories (ia or ic) does not take into account all the relevant information. If part of the point of knowing that heat energy is an extensive variable is the notion that mass plays a role in heat energy transfer, then some of the students who received an "ia" judgement showed evidence of that knowledge. It remains to be seen whether such knowledge is easily changed to the correct knowledge that a larger mass (of the same substance) transfers more heat energy than a smaller mass experiencing the same temperature change. Further evaluation of participants' knowledge of this component of heat energy is discussed in more detail in a later section describing the results from the Beaker Task.

The Relationship Between Heat Energy and Temperature

Master List of Propositions. Tables 3 and 4 contain the results of the analysis of participants' knowledge of the relationship between heat energy and temperature with respect to the Master List of Propositions. The data in Table 3 indicate several patterns for the teacher-student groups. First, within teacher-student groups one pattern was that Ms. Baxter was the only teacher to exhibit knowledge matching the proposition that heat and heat energy are different concepts (proposition 1), and more of her students matched that proposition than the other teachers. This finding supports a relationship between teacher and student knowledge.

Another pattern in the data concerns Ms. Lowry's group. More of her students than in any other group exhibited knowledge matching the correct proposition that the amount of heat energy

determines the change in temperature (proposition 9). Because Ms. Lowry also exhibited that correct knowledge, this result may be evidence of a relationship between teacher and student knowledge. On the other hand, since propositions 6 and 9 are opposites, it is important to consider this conclusion in conjunction with the results for proposition 6. Some of those data appear to confirm the existence of a relationship between teacher and student content knowledge. For example, the majority of Ms. Baxter's students exhibited the incorrect proposition (number 6), and she did *not* exhibit the correct proposition (number 9). In addition, Ms. Gentry and Ms. Mason exhibited the correct proposition in only one interview, and the majority of their students exhibited the incorrect proposition (number 6). On the other hand, Ms. Carlson exhibited the correct proposition and only one of her students matched that knowledge. Thus, the patterns in these are ambiguous with respect to a relationship between teacher and student content knowledge.

A third pattern in the data in Table 3 is seen in the Carlson teacher-student group data: more of the students in that group than any other group exhibited knowledge matching propositions associating heat energy and molecular motion (propositions 22-26). This result could be evidence of a relationship between teacher and student knowledge because Ms. Carlson was the only teacher who exhibited *correct* knowledge of the relationship between heat energy and molecular motion. On the other hand, other teachers exhibited knowledge relating heat energy to molecular motion and their students did *not* exhibit knowledge matching those propositions. Furthermore, whereas Ms. Carlson exhibited correct knowledge of the relationship, her students exhibited mostly incorrect knowledge. Thus, these data do not conclusively provide evidence of a relationship between teacher and student knowledge.

Second, data across the teacher-student groups indicates one pattern that may be indicative of a relationship between teacher and student knowledge. The pattern occurs in the data for proposition 13, the proposition that there is no change in temperature if heat energy is added to a substance at the highest temperature it can be: more of Ms. Carlson's and Mr. Roberts' students exhibited knowledge matching this proposition than students of any of the other teachers. Since none of the teachers exhibited this proposition, there is not an obvious reason for the pattern. Furthermore, because the knowledge exhibited by Ms. Carlson and Mr. Roberts was similar in a number of respects, there are not differences which provide additional insight. Thus, this pattern is not readily explained by a relationship between teacher and student knowledge.

Another pattern evident in the Carlson teacher-student group data is that all of the students to some degree exhibited knowledge that temperature doesn't change during a phase change (proposition 16), and that was knowledge exhibited by Ms. Carlson as well. This pattern is evidence of a relationship between teacher and student content knowledge. On the other hand, two other teachers (Ms. Gentry and Mr. Roberts) exhibited this same knowledge whereas their

students did not. Thus, the pattern in the Carlson teacher-student group data does not generalize to the whole sample as confirming a relationship between teacher and student knowledge.

Finally, the data do *not* show a pattern that might be expected, and which deserves discussion. Both Ms. Carlson and Mr. Roberts exhibited knowledge matching the propositions relating heat energy and temperature to energy transfer (propositions 31 - 33) and yet their students did not typically exhibit such knowledge. The reason for the lack of relationship in the Roberts group data is most likely the lack of instruction about the relationship between the concepts. For the Carlson group data, there is no such an explanation. As it stands, these data (or the lack thereof) indicate there is not a relationship between teacher and student content knowledge.

The data in Table 4 provide information about the overall correctness of the participants' knowledge shown in Table 3. In that respect, there are four noteworthy results. First, Ms. Carlson's group included the student (Shawn) who exhibited the most correct knowledge about the relationship between heat energy and temperature. Because Ms. Carlson was the teacher who exhibited the most correct knowledge, this finding could support a relationship between heat energy and temperature. At the same time, although there is not specific information on Shawn, Ms. Carlson's students were typically above average students, and this result may be a reflection of individual differences rather than a more general pattern. Second, more of Ms. Lowry's students than any other teacher's students exhibited a higher percentage of correct knowledge in the spring interview. This result is not readily explained by Ms. Lowry's content knowledge because she did not exhibit a higher percentage of correct knowledge than the other teachers, and she was one of the teachers who exhibited fewer correct propositions in the spring than the fall. Thus, a relationship between the amount of teacher and student content knowledge was not consistently supported by the data.

Third, Ms. Carlson and Ms. Lowry were the only teachers for whom all of their students exhibited knowledge matching at least one correct proposition in the spring interview. For the reasons described above, this pattern is not readily explained in terms of a relationship between teacher and student content knowledge. Finally, there was also a pattern in the data from the Roberts student-group: Mr. Roberts had the most students (three of his four students) exhibiting *no* knowledge matching correct propositions on the Master List in the fall interview, and in the spring, he had the most students who showed *no* change in the percentage of correct knowledge exhibited. This result was not surprising considering that Mr. Roberts reported that he did not address the distinction between heat energy and temperature. This result is not trivial, however, because it provides some evidence that students' knowledge of the relationship between heat energy and temperature is not likely to improve without instruction about such knowledge.

The Beaker Task. Table 5 shows the results from the Beaker Task. Note that percentages of 33 and 25 both reflect one correct response out of the total. Consequently, those numbers are not meaningfully different when considering changes in performance.

One notable result in these data is in the "correct choice" column of the table: only half of the teachers had students who improved in their choice of a correct answer to the task. Considering that all teachers responded accurately to the situation they were presented in the task, differences in student performance are not attributable to differences in teacher knowledge. Similarly, in the "considered both variables" colum two teachers had students who exhibited *less* correct reasoning after instruction (Ms. Baxter and Ms. Mason), and yet there were not differences in their knowledge that would explain such a result.

Finally, the data in the column about choosing the smaller volume contain two patterns. One pattern is that three of the teachers (Ms. Gentry, Ms. Lowry, and Mr. Roberts) had more students in the spring interview who chose the smaller volume than in the fall interview. The second pattern is that three of the teachers (Ms. Baxter, Ms. Carlson, and Ms. Mason) had no students or no change in the number of students choosing the smaller volume. Again, because there was no variation in teacher knowledge, these data cannot be explained in terms of a relationship between teacher and student knowledge. Thus, these data do not show evidence of a relationship between teacher content knowledge and student content knowledge.

Teachers' knowledge of student understanding compared to students' content knowledge. Table 6 shows the teachers' knowledge of incorrect conceptions exhibited by students. There is some evidence of a relationship between teachers' pedagogical content knowledge of student understanding and student content knowledge based upon the results of the student data for the concepts of heat energy and temperature. Ms. Mason and Ms. Gentry consistently exhibited *less* knowledge of student understanding than the other teachers, and their students more often exhibited less correct knowledge after instruction than the students of the other teachers. Thus, less pedagogical content knowledge was related to less student content knowledge.

With regard to the converse relationship (more pedagogical content knowledge is related to more student content knowledge), there is not strong evidence of a relationship. For example, the teachers who exhibited strong knowledge of student understanding in both interviews (Mrs. Carlson and Ms. Baxter) did not typically have students who exhibited more correct or more improved knowledge than the others. Although the data from Mr. Roberts' students could be considered additional evidence of the lack of a relationship, it was discounted because his instruction did not address the distinction between heat energy and temperature.

In sum, there was not strong support for the relationship that strong pedagogical content knowledge of student understanding was related to more correct or more improved content knowledge of students. There was some support for the relationship that *less* pedagogical content

knowledge of student understanding was related to *less* correct or *less* improved student content knowledge in the spring interview. Most likely, however, these results indicate a more complex relationship than one between teacher pedagogical content knowledge and student content knowledge is needed to explain patterns in the data.

Teachers' knowledge of topic-specific pedagogical strategies compared to students' content knowledge. Table 7 shows the teachers' knowledge of strategies for teaching about heat energy and temperature. The comparison of teacher knowledge to student content knowledge was carried out with respect to the data on alternative conceptions, and the propositions about the relationship between heat energy and temperature.

Examination of those data indicates little evidence of a relationship between this component of pedagogical content knowledge and student content knowledge. The teacher who exhibited the greatest amount of knowledge related to this component (Ms. Carlson) did not have the students who exhibited the greatest increase in knowledge. She did have the single student who exhibited the greatest increase in knowledge of heat energy, but that result could be attributable to individual differences. Furthermore, the teacher whose students exhibited the most change toward *less* correct knowledge of the relationship between heat energy and temperature (Ms. Baxter), was one of the teachers who exhibited an *increase* in knowledge of pedagogical strategies. Similarly, the teacher whose students exhibited the most change toward *less* correct knowledge of heat energy (Ms. Mason), exhibited increased knowledge with regard to this component of pedagogical content knowledge. Thus, these data do not support the hypothesis that a relationship exists between teachers' knowledge of topic-specific pedagogical strategies and their students' content knowledge.

Teachers' content framework and students' propositions about the relationship between heat energy and temperature. Table 8 shows the teachers content frameworks about heat energy and temperature. Categories of content frameworks described by each teacher were compared to the categories of propositions exhibited by his or her students to identify patterns relevant to a relationship between teacher and student knowledge. Only one pattern was identified: Ms. Carlson described the molecular framework for learning about heat energy, and all of her students exhibited some knowledge associating heat energy and molecular motion. In addition, Ms. Carlson's students all exhibited knowledge at the end of the year that heat energy causes temperature, and that knowledge is consistent with the incorrect knowledge that heat energy is molecular motion. Although Ms. Carlson exhibited correct knowledge of the relationship between heat energy and temperature, the results for her students suggests that they acquired similar but incorrect knowledge. This finding illustrates an unintended consequence of the molecular framework of representing heat energy: it reinforces the idea that heat energy is contained in a body.

Other teachers exhibited the molecular framework but did not have students who showed a pattern of associating heat energy and molecular motion, and that finding is noteworthy. There are two possible reasons for this result. One explanation is that it indicates that the relationship between teacher content frameworks and students' content knowledge is not straightforward. Another explanation is that other factors contributed to the relationship evident with Ms. Carlson and her students. Both reasons probably contribute to the results in this case.

Relationship Between Teacher Activities and Student Content Knowledge

Table 9 shows the MBL activities conducted by each teacher during the year in which the data used in this study were collected. Data were not collected about how the teachers chose the set of activities they conducted for instruction in heat energy and temperature, consequently, the same activity conducted by different teachers may have had different learning goals.

Although the teachers were very similar in the total number of activities they conducted (with the exception of Ms. Baxter), there was substantial variation in the number of activities they conducted which emphasized the distinction between heat energy and temperature. The patterns that stood out the most concerned those teachers who performed the most or the least number of activities emphasizing the distinction between heat energy and temperature. Ms. Lowry conducted the most activities with that emphasis, and her students generally showed the most improvement in content knowledge (knowledge of temperature, heat energy, and the relationship between the concepts). Mr. Roberts conducted *no* activities with that emphasis, and his students exhibited the least amount of change in content knowledge.

These results suggest there is a relationship between the number of activities conducted by a teacher and changes in the knowledge of students. The relationship concerned not the total number of activities about heat energy and temperature, but rather, the total number of activities emphasizing the distinction between heat energy and temperature. Because this conclusion was supported only by data from the teachers who conducted the most or the least number of activities emphasizing the distinction, and there is not a straightforward pattern for the teacher data in the middle (number-wise), there is probably a more complex relationship operating to explain the student results. At minimum, however, the findings from this study do suggest that if students do not complete *any* activities emphasizing the distinction between heat energy and temperature, their knowledge of heat energy or the relationship between heat energy and temperature is not likely to change.

Conclusions

The Relationship Between Teacher and Student Content Knowledge

There was evidence of a relationship between teacher content knowledge and changes in student knowledge; however, that relationship only existed in the event of incorrect teacher knowledge. For example, the teachers who exhibited the most correct knowledge about heat energy and temperature

did *not* have the students whose knowledge changed the most. The pattern that emerged was that teachers with incorrect content knowledge, particularly alternative conceptions, had students who showed little improvement or decreased in content knowledge. Specifically, all the teachers who exhibited knowledge of the alternative conception that temperature measures heat energy had students whose knowledge of temperature was less correct at the end of the year than at the beginning. Further, the group of students who exhibited the greatest *decrease* in correct knowledge about heat energy were students of the only teacher whose knowledge of heat energy was less correct at the end of the year than at the beginning (just before she taught the content).

The Relationship Between Teacher Pedagogical Content Knowledge and Student Content Knowledge

There was slight evidence of a relationship between teacher pedagogical content knowledge and changes in student knowledge. For example, the teacher with the students who showed the most improvement in knowledge exhibited a substantial amount of desired pedagogical content knowledge. Further, two teachers who lacked knowledge of student understanding related to heat energy and temperature had the students who showed the *least* improvement in knowledge. One explanation of this second result is that the teachers' lack of knowledge about student understanding , specifically, students' incorrect knowledge, limited their ability to address student knowledge deficiencies. It was the case that both of these teachers had students who exhibited the knowledge that the teachers thought it was unlikely for students to hold. This second result also provides evidence that knowledge of student understanding is important pedagogical content knowledge for science teachers, and that it is knowledge that teachers may not possess.

Teaching Activities and Changes in Student Knowledge

The strongest evidence of a relationship in this study was between changes in student knowledge and the amount of a particular type of instruction. The students who experienced the most and least number of laboratory activities that emphasized the distinction between heat energy and temperature exhibited the most and least improvement in knowledge, respectively. This finding provides evidence of the importance of laboratory activities in science. However, it also includes the qualification that activities are not equally beneficial in helping students acquire correct content knowledge about heat energy and temperature. The relationship existed only with those activities that emphasized the *distinction* between heat energy and temperature. Those students who did not experience such activities, even though they experienced activities involving heat energy and temperature, showed little or not change in knowledge.

This finding also indicates that MBL activities can be powerful tools for learning about heat energy and temperature because most of the instructional activities which emphasized the distinction between heat energy and temperature were MBL activities, some of which are *only* feasible as MBL activities because they require a special peripheral (heat pulser) with the microcomputer. Because some of the activities are only feasible as MBL activities, the findings in this study demonstrate that MBL

instruction can be more powerful than traditional instruction for promoting the acquisition of scientific knowledge of heat energy and temperature.

Teaching Activities and the Relationships Between Teacher and Student Knowledge

The relationship between teaching activities and student knowledge, however, does not completely represent the findings in this study. By itself, the relationship is misleading. There was only a difference of one activity between the teacher who conducted the most laboratory activities emphasizing the distinction between heat energy and temperature (6), and the teacher who was second (5); not a difference that would likely result in vastly different study outcomes. Yet, the students of those teachers exhibited very different changes in knowledge. The differences can be explained if teacher knowledge is taken into account. Thus, the most comprehensive explanation of the patterns in the data is a relationship between student knowledge and instruction as a function of teacher knowledge.[8]

The following patterns illustrates this relationship:

- The teacher whose students exhibited the most improved knowledge of the concepts of heat energy and temperature, conducted the most activities emphasizing the distinction between heat energy and temperature. Consequently, she had the most opportunity of any of the teachers to use her knowledge to facilitate knowledge acquisition by her students. Her content knowledge was acceptable and her pedagogical content knowledge was good, so the impressive performance of her students is not surprising. In contrast, a teacher who conducted the second highest number of activities emphasizing the distinction between heat energy and temperature, but who exhibited less correct content knowledge and weaker pedagogical content knowledge, had students who did not exhibit a similarly large increase in knowledge.
- A teacher who was among those exhibiting the greatest amount of correct content knowledge and desired pedagogical content knowledge, but who conducted *no* activities emphasizing the distinction between heat energy and temperature, had the students who exhibited the least change in knowledge. Because he conducted no activities emphasizing the distinction, this teacher had few opportunities to use his knowledge to facilitate the acquisition of knowledge by his students.

Summary

Although there was evidence of a relationship between teacher and student knowledge, the patterns in this study were best explained when the teachers' instructional activities were taken into account. If teacher knowledge was strong but the opportunities to exhibit it under certain conditions (instructional activities with a specific characteristic) were few, student knowledge did *not* change. If

[8] Because the teachers' choices to use particular laboratory activities were not investigated, they cannot be described meaningfully as part of the teachers' knowledge. However, in future studies that would be an important element to include.

teacher knowledge was strong and opportunities to exhibit it were many, student knowledge *did* improve. If teacher knowledge was *not* strong and opportunities were many, student knowledge did *not* improve substantially, and in some cases become less correct.

At the same time, this perspective did not explain all the patterns in the data. For example, one group of students exhibited substantially more knowledge relating heat energy to molecular motion than any of the other students. Their teacher exhibited similar content knowledge but she was not the only teacher to do so (although she was the only teacher who exhibited correct knowledge of the relationship). Further, although that teacher discussed relating heat energy to molecular motion as an approach for teaching about heat energy and temperature, she was not the only teacher to do so, and, that approach was not the one she emphasized in her interviews. Thus, differences in her content and pedagogical content knowledge did not explain differences in her students' knowledge, and none of the MBL activities addressed the relationship between heat energy and molecular motion. Perhaps what she reported emphasizing in her instruction differed from what she actually emphasized. Perhaps there was other instruction she conducted that was not reported. Further research incorporating classroom observations is needed to fully explore the relationship between teacher and student knowledge and instruction.

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Distinguishing Heat Energy & Temperature Task

CONTENT KNOWLEDGE

(a) Describe temperature.

(b) Describe heat energy.

(c) Describe the distinction between heat energy and temperature

(d) Give an example that shows how heat energy and temperature are different.

PEDAGOGICAL CONTENT KNOWLEDGE

(a) What would you or do you do in your teaching to help students distinguish between heat energy and temperature?

Beaker Task

CONTENT KNOWLEDGE

Given two beakers of water which begin at the same temperature and are allowed to cool to room temperature (the water in one beaker is double that of the water in the other beaker and they begin at the same temperature),

(a) Describe the loss of heat energy that would occur for the water in each beaker.

(b) Please explain your response.

PEDAGOGICAL CONTENT KNOWLEDGE

(a) How do you predict most students would respond to the beaker question on a pretest?

(b) Given the common inaccurate response by students that the water in both beakers loses the same amount of heat energy, what does that mean to you about the students' thinking?

(c) What would you do in your teaching to help students gain a better understanding of the concepts in the question?

Cooling Curve Task

CONTENT KNOWLEDGE

Given this result for the cooling of 100 milliliters of water starting at 80°C (curve on a temperature versus time graph),

(a) What do you think the result would look like for 20 milliliters of water in the same situation under the same conditions?

(b) Please explain your response.

PEDAGOGICAL CONTENT KNOWLEDGE

(a) How do you predict most students would respond to the cooling curve question on a pretest?

(b) Given what is shown on this graph as a common inaccurate response by students, what does that mean to you about the students' thinking?

(c) What would you do in your teaching to help students gain a better understanding of the concepts in the question?

Decontextualized Graph Task

CONTENT KNOWLEDGE

Given this graph (heating curve with flat sections at the beginning and end of the curve),

(a) Tell me what it means to you. Tell me what you see.

(b) Compare and explain what's happening in the different sections of the curve.

(c) Give an example of a situation that would produce a curve like this.

PEDAGOGICAL CONTENT KNOWLEDGE

(a) What would you do in your teaching to help students gain the knowledge needed to respond accurately to the questions you were just asked about the graph?

Figure 1. Summary of the major components of the tasks in the semi-structured interview.

Components of the Concept of TEMPERATURE

A) Temperature is a measure of hotness or coldness of a system. (Halliday & Resnick, 1981, p. 341)
- *Temperature has to do with things feeling hot or cold.*

B) Temperature is measured by thermometer. (Halliday & Resnick, 1981, p. 350)
- *A thermometer shows heat and cold.*
- *Temperatures are being recorded by a thermometer.*

C) The magnitude of the temperature does not depend on the amount of material present. (Chang, 1981, p. 9) [intensive property]
- *Temperature is true at one particular point--wherever you put the thermometer.*

Components of the Concept of HEAT ENERGY

A) Energy that flows from one object to another because of the temperature difference between them; the greater the temperature difference the more heat energy transferred. (Halliday & Resnick, 1981, p. 368)
- *Upon cooling to room temperature, the water at the higher temperature will have lost more heat energy than the water at the lower temperature.*

B) Heat energy added or taken away from an object raises or lowers temperature, respectively. (Beiser, 1978, p. 331)
- *The temperature's staying the same because there's no heat being gained or no heat being lost.*
- *It starts from one point and it's heated up to a greater point.*

C) Heat energy is typically measured in calories.
- *We calculated the heat energy lost in calories.*

D) The temperature change resulting from heat transfer depends on the mass (volume) of the body. (Halliday & Resnick, 1981, p. 357)
- *The larger volume takes more heat to get to the same temperature as the smaller volume and what you put in is what you get out so it would give off more heat energy.*

E) Relationship of specific heat to determination of heat energy. (Halliday & Resnick, 1981, p. 368)
- Different materials have different specific heats because of their make-up.
- *The same amount of heat energy added to different materials does not result in the same change in temperature.*

ALTERNATIVE CONCEPTIONS About Heat Energy and Temperature

A) Temperature is a measure of heat energy.
- *The thermometer reads the heat energy present.*

B) Heat energy is made of particles.
- *Heat energy is like a molecule hooked up to another molecule of water so the water becomes full of heat energy.*

C) Temperature is the average kinetic energy and heat energy is the total kinetic energy in a system.
- *Temperature is the average amount of energy in one spot, and the amount of energy an object possesses is heat energy.*

Figure 2. Components of the framework for analyzing knowledge of heat energy and temperature.

I. HEAT and HEAT ENERGY are DIFFERENT.		#1
II. HEAT ENERGY and TEMPERATURE are MEASURED DIFFERENTLY.		**#2***
III. TEMPERATURE (T) INDICATES WHETHER HEAT ENERGY (HE) is PRESENT.		
	HE relates to hotness, T relates to hotness and coldness.	#3
	If the amount of HE added = T, there is no ΔT.	#4
	Cold means no heat but there may be HE.	#5
	T tells the amount of HE.	#6
	ΔT means HE can escape.	#7
	ΔT tells the amount of HE, volume affects the time for ΔT.	#8
IV. HEAT ENERGY CAUSES ΔT.		
	The ΔT (not T) tells about the amount of HE.	**#9***
	ΔHE added tells about the change of rate of ΔT.	#10
V. The SUBSTANCE and HEAT ENERGY INFLUENCE the TEMPERATURE.		
	Substance and HE influence ΔT.	
	Takes time for HE to disperse in or out of substance and cause a ΔT.	#11
	Takes time to add enough HE to affect substance and cause a ΔT.	#12
	No ΔT if HE is added when a substance is at the highest T it can be.	#13
	No ΔT if a substance is at the limit of the amount of HE it can absorb.	#14
	No ΔT until substance starts changing state.	#15
	No ΔT while substance is changing state.	**#16***
	Change in rate of ΔT is due to changes in the ratio of liquid to solid present.	#17
	Volume and T influence HE.	
	Volume (or mass) and ΔT tell about the amount of HE gained or lost.	**#18***
	Volume and ΔT affect time to cool which tells about the amount of HE gained or lost.	**#19***
	Volume (or mass), ΔT, & specific heat determine the amount of HE gained or lost.	**#20***
VI. TEMPERATURE, HEAT ENERGY, and MOVEMENT		
	T is static, HE is active.	#21
	HE is molecular motion.	#22
	Friction from the collisions of molecules makes HE.	#23
	Amount of HE ~ speed of molecules.	#24
	Amount of HE ~ number of molecules.	#25
	HE can influence molecular motion.	**#26***
VII. TEMPERATURE, HEAT ENERGY and ENERGY		
	HE is energy from something hot.	#27
	T tells about the heat, HE is energy.	#28
	T is average kinetic energy and HE is total kinetic energy.	#29
	T is the amount of energy at a point; HE is the amount of energy in the whole substance.	#30
VIII. TEMPERATURE, HEAT ENERGY and ENERGY TRANSFER		
	HE is a transfer of energy because of a difference in T.	**#31***
	ΔT occurs when there is a difference in the amount of HE supplied & HE released.	**#32***
	Amount of ΔT in a HE transfer is influenced by the type of substance and its mass.	**#33***

Figure 3. Master List of propositions about the relationship between heat energy and temperature. The categories of propositions are in capital letters, and the correct propositions are shown in bold, and their numbers are followed by an asterisk.

(a) Knowledge of **alternative content frameworks** for thinking about teaching a particular subject includes:
- knowledge about the purposes and goals for teaching particular subject matter
- knowledge about the purposes for learning a subject at a particular grade level
- knowledge about what's important for students to know, understand, & appreciate about the subject matter
- knowledge about the interrelationships of topics within a subject and what students should ideally understand about those relationships
- knowledge about how the study of a subject fits into larger educational goals

(b) Knowledge of **student understanding and misconceptions** of a subject
- knowledge about how students learn subject matter and the intellectual abilities or skill students must possess in order to do well in a subject
- knowledge of the concepts, topics, and skills that prove especially difficult for students to understand and acquire
- knowledge of how students of differing ability levels may vary in their approach to learning the subject, e.g. different strategies students may use to overcome difficulties understanding the subject matter

(c) Knowledge of **curriculum**
- knowledge of the curricular materials available for teaching a particular subject
- knowledge concerning curricular guidelines and mandates at the state, district, and school level
- knowledge about the vertical curriculum in their subjects--what students have learned previously and what they are expected to learn in later years

(d) Knowledge of **particular content** - refers to the situation of teachers acquiring new knowledge that is organized for teaching purposes and not to reflect the discipline.

(e) Knowledge of topic-specific **pedagogical strategies** - repertoire of representations, such as analogies, demonstrations, experiments, among other possibilities, which a teacher uses to teach particular topics, e.g. teachers may develop very specific strategies for helping students learn particularly difficult material

Figure 4. Components of pedagogical content knowledge taken from "Knowledge Growth in Teaching: A Final Report to the Spencer Foundation" by Lee Shulman (1988, pp. 19-22).

Laboratory Activity Categories	Example Activity
1. *Different volumes at the same T; compare ΔT_{mix} after mixing with another volume.*	Add two volumes of water at the same temperature to the same amount of ice water (e.g., 10 mL) and compare differences in the change of temperature that results.
2. *Different volumes maintained at the same T; compare amount HE required to maintain T.*	Use the heat pulser to keep two different volumes of water at the same temperature, and compare the number of pulses required to keep each volume at that temperature for the same amount of time.
3. Different volumes with the same ΔT; compare the amount time for ΔT, infer about amount of HE transferred.	Let two different volumes of water at the same starting temperature (e.g., 50°C) cool to room temperature. Compare the amount of time each takes to cool and use that information to conclude about the amount of heat energy lost.
4. *Different volumes with the same ΔT; compare amount of HE transferred.*	Let two different volumes of water at the same starting temperature (e.g., 50°C) cool to room temperature. Calculate the amount of heat energy lost by each and compare the results.
5. *Different volumes w/ same amount of HE added; compare ΔT.*[d]	Using the heat pulser, add the same number of heat pulses to two different volumes of water and compare the change in temperature for each.
6. *Different substances w/ same amount of HE added; compare ΔT.*[d]	Using the heat pulser, add the same number of heat pulses to the same amount of different substances (e.g., water & alcohol) and compare the change in temperature for each.
7. Same volume w/different amounts of HE added; compare ΔT.	Using the heat pulser, add a different number of heat pulses to the same amount of water and compare the changes in temperature.
8. *Calorimetry (calculate HE).*	Burn a peanut below a beaker of water so that the water absorbs the heat energy lost by the peanut; calculate the heat energy gained by the water to determine how much was lost by the peanut.
9. *Phase change; note ΔHE but no ΔT.*	Monitor the temperature before, during, and after a change in phase (e.g., ice melting or water boiling).

<u>Figure 5</u>. Categories of laboratory activities described by teachers as useful for teaching about the distinction between heat energy and temperature.

	MICROSCOPIC	MACROSCOPIC		
CONTENT	Heat energy is associated with molecular motion.	T is one factor influencing HE.	HE is the energy of the whole; T, is the energy of a part.	HE is energy transfer associated with a ΔT.
Framework Name	Molecular Framework	Factor Framework	Energy Framework	Transfer Framework
Correct representation of HE?	NO	YES	NO	YES
Correct representation of T?	does not describe T	does not describe T	YES	does not describe T
Correct representation of the relationship between the concepts?	NO	YES	NO	YES
Challenges incorrect knowledge?	NO	NO	NO	YES

Figure 6. Content frameworks for teaching about heat energy (HE) and temperature (T).

Table 1

Teachers' and Students' Knowledge Related to the Concept of Temperature

Participants	Correct Concepts								Alternative Conception	
	How hot or cold		Measured with a thermometer		Intensive variable		Average kinetic energy		Measure of heat energy	
	F	S	F	S	F	S	F	S	F	S
Ms. Baxter	√	√	√	√	√	√	-	-	ic	-
Brad	√	√	√	√	-	-	-	-	-	√
Charlene	√	√	√	√	-	-	-	-	√	-
David	inc.	√	√	√	-	-	-	-	-	-
Pam	√	√	√	√	-	-	-	-	√	√
Ms. Carlson	√	√	√	√	-	√	√	√	-	-
Philip	√	√	√	√	-	-	-	-	√	√
Shawn	-	-	√	√	-	-	-	-	√	√
Vicki	-	-	√	√	-	-	-	-	√	-
Ms. Gentry	√	√	√	√	-	-	-	√	ic	-
Annette	√	√	√	√	-	-	-	-	-	-
Jacki	√	√	√	√	-	-	-	-	√	-
Rochelle	√	√	√	√	-	-	-	-	-	(wk)
Ms. Lowry	√	√	√	√	√	-	-	-	-	-
Allen	√	√	√	√	-	-	-	-	√	-
Andrew	√	√	√	√	-	-	-	-	√	√
Erik	√	√	√	√	-	-	-	-	√	-
Rachel	√	√	√	√	-	-	-	-	√*	-
Ms. Mason	√	√	√	√	√	-	√	-	-	ic
Carynne	√	√	√	√	-	-	-	-	-	-
Mary	√	√	√	√	-	-	-	-	-	√
Philip	-	√	(wk)	√	-	-	-	-	√	√*
Steve	√	√	√	√	-	-	-	-	-	-
Mr. Roberts	√	√	√	√	-	-	-	-	-	-
Ginelle	√	√	√	√	-	-	-	-	-	-
Lance	√	√	√	√	-	-	-	-	-	-
Rob	√	√	√	√	-	-	-	-	-	-
Sam	√	√	√	(wk)	-	-	-	-	-	-

Key:

√	Knowledge present	ia	Inaccurate - Knowledge present was incorrect.	HE	Heat energy.
√*	Presence of knowledge in slightly altered form.	ic	Inconsistent - Knowledge evident but not used consistently.	T	Temperature
(wk)	Evidence of knowledge was slim.	inc	Incomplete - Knowledge present was correct but incomplete.		
-	No explicit evidence of knowledge.				

Table 2

Teachers' and Students' Knowledge Related to the Concept of Heat Energy

Participants	Correct Concepts										Alternative Conceptions					
	ΔT ≈ HE gained or lost		Influence on T		Unit-calorie		HE is an extensive variable		Role of specific heat		HE is made of particles		HE is total KE		Measured by T	
	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S
Ms. Baxter	√	√	√	√	√	√	√	√	-	-	-	-	-	√*	ic	-
Brad	√	ic	√	√	-	-	√	ic	-	-	-	-	-	-	-	√
Charlene	√	√	√	√	-	-	ia	ia	-	-	-	-	-	-	√	-
David	√	ia	√	√	-	-	ia	ia	-	-	√	√	-	-	-	-
Pam	ic	√	√	√	-	-	ic	ic	(wk)	-	√	-	-	-	√	√
Ms. Carlson	√	√	√	√	-	-	√	√	√	√	-	-	-	-	-	-
Philip	√	√	√	√	-	-	ia	ia	-	-	-	-	-	-	√	√
Shawn	√	√	√	√	-	-	√	√	-	-	-	-	-	-	√	√
Vicki	√	√	√	√	-	√	ia	√	-	-	-	-	-	-	√	-
Ms. Gentry	√	√	√	√	-	-	√	√	-	-	-	-	√	√	ic	-
Annette	√	√	√	√	-	-	ic	ia	-	-	-	-	-	-	-	-
Jacki	√	√	√	√	-	-	ia	ic	-	-	-	-	-	-	√	-
Rochelle	√	√	√	√	-	-	ia	ia	-	-	-	-	-	-	-	(wk)
Ms. Lowry	√	√	√	√	-	-	√	√	√	(wk)	-	-	√*a	√*a	-	-
Allen	√	√	√	√	-	-	ia	ia	-	-	-	-	-	-	√	-
Andrew	√	√	√	√	-	-	ia	√	-	-	-	-	-	-	√	√
Erik	√	√	√	√	-	-	ic	√	-	-	-	-	-	-	√	-
Rachel	√	√	√	√	-	-	ia	ia	-	-	-	-	-	-	√*	-
Ms. Mason	√	√	√	√	√	√	√	√	√	√	-	-	-	-	-	ic
Carynne	√	√	√	√	-	-	√	ia	-	-	-	-	-	-	-	-
Mary	ia	ia	√	√	-	-	ia	ia	-	-	-	-	-	-	-	√
Philip	√	√	√	√	-	-	ia	√	-	-	-	-	-	-	√	√*
Steve	√	√	√	√	-	-	√	√	-	-	-	-	-	-	-	-
Mr. Roberts	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-
Ginelle	√	√	-	√	-	-	ia	ia	-	-	-	-	-	-	-	-
Lance	√	√	√	√	-	-	ic	ia	-	-	-	-	-	-	-	-
Rob	√	√	√	√	-	-	ia	ia	-	-	-	-	-	-	-	-
Sam	√	ia	√	√	-	-	ia	ia	-	-	-	-	-	-	-	-

Key:

√	Knowledge present	ia	Inaccurate - Knowledge present was incorrect.	ΔT	Change in temperature.
√*	Presence of knowledge in slightly altered form.	ic	Inconsistent - Knowledge evident but not used consistently	HE	Heat energy.
(wk)	Evidence of knowledge was slim.			KE	Kinetic energy.
-	No explicit evidence of knowledge.	inc	Incomplete - Knowledge present was correct but incomplete.	T	Temperature.

[a] Defined heat energy as the average kinetic energy of the molecules of a substance.

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Table 3

Participants' Knowledge About the Relationship Between Heat Energy and Temperature

Participants	Intv.	1	2*	3	4	5	6	7	8	9*	10	11	12	13	14	15	16*	17	18*	19*	20*	21	22	23	24	25	26*	27	28	29	30	31*	32*	33*
Ms. Baxter	F	√	√														√		√	√			√		√	√						p		
	S		√													ic	ic		√		ic										√	p		
Brad	F	√					√				√			√					√															
	S			√			√		ic		√	√		√					ic															
Charlene	F	√					√		√							√						√							√					
	S	√	√				√									√						√							√					
David	F						√							√																				
	S	√					√		√													√							√					
Pam	F	√			√					√	√	√							√			√							√					
	S	√			√					√	√	√			√				ic			√							√					
Ms. Carlson	F									√							√		√	√	√						√					√	√	
	S									√							√		√		√						√					√		√
Philip	F						√						√	√		√	p																	
	S						√						√	√	√								√		√		√							
Shawn	F						√						√	√			√		√								√						√	
	S						√							√			√		√				√		√									
Vicki	F						ic							√			p						√		√									
	S									√			√				p		√				√		√	√								
Ms. Gentry	F										√						√		√											√		p		
	S									√	√						√		√				√		√					√				
Annette	F									√		√		√														√						
	S	√		√		√	√							√			√					√												
Jacki	F	√		√			√				√																		√					
	S	√	√	√			√		√			√		√																				
Rochelle	F			√							√																							
	S			√												√						√												
Ms. Lowry	F									√	√						√		√		√		√							√	√	p		
	S									√							ic		√		√		√		√					√				
Allen	F	√				√				√	√																							
	S									√		√			√																			
Andrew	F	√		√		√	√		√					√	√													√						
	S			ic						√			√				p		√															
Erik	F	√				√				√	√	√							ic													p		
	S									√		√				√		√		√				√			ic							
Rachel	F	√				√			√	√	√			√															√					
	S	√	√			√				√				√		√																		

(table continues)

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Participants	Intv.	1	2*	3	4	5	6	7	8	9*	10	11	12	13	14	15	16*	17	18*	19*	20*	21	22	23	24	25	26*	27	28	29	30	31*	32*	33*
Ms. Mason	F		√							√		wk					√		√		√		√								√			
	S		√														√		√		√		wk											
Carynne	F			√						√						√		√										√						
	S						√	√		√								√																
Mary	F			√				√								√																		
	S	√					√									√																		
Philip	F			√			√				√					√		√																
	S						√							√		√		√	√															
Steve	F						√									√			√									√						
	S		√				√									√			√													p		
Mr. Roberts	F		√							√	√						√		√													√		
	S		√							√							√		√													√		
Ginelle	F	√								√				√																				
	S			√						√												√												
Lance	F	√					√					√		√								√							√					
	S	√								√		√		√								√					√		√					
Rob	F						√							√		√		√											√					
	S			√			√											√																
Sam	F	√		wk			√							√																				
	S											√		√																				

1 Heat Energy (HE) and heat are different.
2* HE and Temperature (T) are measured differently.
3 HE relates to hotness, T relates to hotness and coldness.
4 If HE added = T, there's no ΔT.
5 Cold means no heat but there may be HE.
6 T tells the amount of HE.
7 ΔT means HE can escape.
8 T indicates the amount of HE, volume affects the time for ΔT.
9* The ΔT (not T) tells about the amount of HE.
10 Δ HE added tells about the rate of ΔT.
11 Takes time for HE to cause a ΔT.
12 Takes time to add enough HE to cause a ΔT.
13 No ΔT if HE is added when the substance is at the highest T it can be.
14 No ΔT if a substance is at the limit of the amount HE it can absorb.
15 No ΔT until a substance <u>starts</u> changing state.
16* No ΔT <u>while</u> a substance changes state.
17 Change in rate of ΔT is due to changes in the ratio of liquid to solid present.
18* Vol. and ΔT tell the amount of HE lost/gained (in water)
19* Vol. and ΔT affect time to cool which tells the amount of HE gained/lost (in water).
20* Mass, ΔT, and specific heat determine the amount of HE gained/lost.
21 T is static, HE is active.
22 HE is molecular motion.
23 Friction from molecules hitting against each other makes HE.
24 Amount of HE = speed of molecules.
25 Amount of HE = number of molecules.
26* HE can influence molecular motion.
27 HE is energy from something hot.
28 T tells about the heat, HE is energy.
29 T is the average KE and HE is the total KE.
30 T indicates the amount of energy at a point; HE is the amount of energy in the substance.
31* HE is a transfer of energy due to a T difference.
32* ΔT occurs when there is a difference in the amount of HE supplied and HE released.
33* Amount of ΔT in a HE transfer is influenced by the type of substance and its mass.

Key:

√ Participant exhibited knowledge matching the proposition.
k Participant was inconsistent in exhibiting knowledge matching the proposition.
p Participant exhibited knowledge only partially matching the proposition.
wk Evidence of knowledge matching the proposition was present but weak.

Table 4

Number of Correct Propositions Exhibited By Participants about the Relationship Between Heat Energy and Temperature

	FALL			SPRING			
Participants	#	%[a]	% of total[b]	#	%	% of total	Direction of change[c]
Ms. Baxter	**4/9**	**44**	**40**	**3/5**	**43**	**30**	**–**
Brad	1/5	20	10	0/7	0	0	–
Charlene	0/6	0	0	1/6	17	10	+
David	0/2	0	0	0/7	0	0	o
Pam	2/8	25	20	1/9	11	10	–
Ms. Carlson	**8/8**	**100**	**80**	**7/7**	**100**	**70**	**–**
Philip	0/5	0	0	1/7	14	10	+
Shawn	4/7	57	40	2/6	33	20	–
Vicki	0/5	0	0	1/7	14	10	+
Ms. Gentry	**2/5**	**40**	**20**	**3/7**	**43**	**30**	**+**
Annette	1/4	25	10	1/7	14	10	o
Jacki	0/5	0	0	1/7	14	10	+
Rochelle	0/2	0	0	0/3	0	0	o
Ms. Lowry	**4/9**	**44**	**40**	**3/7**	**43**	**30**	**–**
Allen	1/4	25	10	1/3	33	10	o
Andrew	0/8	0	0	2/5	40	20	+
Erik	1/7	14	10	2/7	29	20	+
Rachel	1/7	14	10	2/6	33	20	+
Ms. Mason	**4/8**	**50**	**40**	**3/5**	**60**	**30**	**–**
Carynne	1/5	20	10	1/4	25	10	o
Mary	0/3	0	0	0/3	0	0	o
Philip	0/5	0	0	1/5	20	10	+
Steve	1/4	25	10	2/5	40	20	+
Mr. Roberts	**5/5**	**100**	**50**	**5/5**	**100**	**50**	**o**
Ginelle	1/3	33	10	1/3	33	10	o
Lance	0/6	0	0	2/7	29	20	+
Rob	0/5	0	0	0/3	0	0	o
Sam	0/4	0	0	0/2	0	0	o

[a] This column represents the percentage of correct propositions exhibited with respect to the total number of propositions exhibited among those on the Master List.

[b] This column represents the percentage of correct propositions exhibited with respect to the number that could have been exhibited from among those on the Master List. The total number of correct propositions on the Master List was 10.

[c] This column shows the change in percentage of correct propositions out of the total of 10 possible correct propositions on the Master List.

Table 5

Performance on the Beaker Task

Participants[a]	Changed Response (%)		Correct Answer Choice (%)		Considered Both Variables[b] (%)		For same ΔT, Smaller Volume Loses More HE[c]	
	F	S	F	S	F	S	F	S
Ms. Baxter	0	0	100	100	100	100	N	N
Brad	0	50	67	25	100	50	N	N
Charlene	67	50	33	0	0	50	N	N
David	33	50	33	0	0	0	N	N
Pam	100	50	33	25	50	50	N	N
Ms. Carlson	0	0	100	100	100	100	N	N
Philip	0	0	33	25	0	0	N	N
Shawn	0	0	100	100	100	100	N	N
Vicki	0	0	33	75	0	100	N	N
Ms. Gentry	0	0	100	100	100	100	N	N
Annette	33	25	67	25	0	50	N	Y
Jacki	33	25	33	25	0	50	N	N
Rochelle	0	0	33	0	100	100	N	Y
Ms. Lowry	0	0	100	100	100	100	N	N
Allen	33	25	33	25	0	0	N	N
Andrew	33	50	33	75	0	100	N	N
Erik	0	25	67	100	0	100	N	N
Rachel	33	0	33	25	0	0	N	Y
Ms. Mason	0	0	100	100	100	100	N	N
Carynne	0	0	67	25	100	50	N	N
Mary	0	0	0	0	100	50	Y	Y
Philip	0	33	33	100	0	100	N	N
Steve	0	0	100	100	100	100	N	N
Mr. Roberts	0	0	100	100	100	100	N	N
Ginelle	0	0	33	25	0	0	Y	[illegible]
Lance	50	50	75	25	0	50	N	Y
Rob	0	0	33	25	0	0	N	N
Sam	0	0	25	0	50	100	Y	Y

KEY: N No.
Y Yes.

[a] Teacher data consists of only one situation for the task whereas student data consists of 3 or 4 situations.

[b] This percentage was calculated using only the results from Situation 2 and 3 of the Beaker Task. The two variables referred to are temperature and volume.

[c] These results are from only the data for Situation 1 and 4 of the Beaker Task. In those situations, the only difference between the water in the beakers was the volume . A code of "no" in this column either means that a student chose the larger volume or that a student stated that both volumes would lose the same amount of heat energy.

Table 6

Teachers' Knowledge of Incorrect Conceptions Exhibited By Students

		DISTINGUISHING HE & T TASK		BEAKER TASK: Both volumes lose same amount of HE.		BEAKER TASK: Smaller volume loses more HE.	
	INTV.	HE = T[a]	Other[b]	ID[c]	Explain[d]	ID	Explain
Ms. Baxter	F	√		√	√	√	√
	S	√	1	√	√	*	*
Ms. Carlson	F	√	1	√	√		√
	S	√		√	√	not a likely response	√
Ms. Gentry	F	√		√	√		
	S	√		√	√	not a likely response	
Ms. Lowry	F	√		√	√		
	S	√		√	√	√	√
Ms. Mason	F	√		√	√	not a likely response	
	S			√	√		
Mr. Roberts	F	√	1	√	√	√	√
	S	√		√	√	√	√

√ Indicates that the teacher exhibited the designated knowledge.

* Probing of this teacher stopped after the first response (both lose same amount) was given; hence, this teacher was not afforded the same opportunity as the others to exhibit knowledge of student understanding related to the Beaker Task.

[a] This equation means that heat energy is not distinguished from temperature.

[b] This column pertains to incorrect conceptions other than the lack of distinction between heat energy and temperature.

[c] This column pertains to the identification of the incorrect response.

[d] This column pertains to the explanation of students' reasoning that caused the incorrect response.

Table 7

Teachers' Knowledge of Strategies for Teaching About Heat Energy and Temperature

	TEACHERS											
	Baxter		Carlson		Gentry		Lowry		Mason		Roberts	
STRATEGIES[a]	F	S	F	S	F	S	F	S	F	S	F	S
Laboratory Activities												
1. *Different volumes at the same T; compare ΔT_{mix} after mixing with another volume.*			√*	√*			ia	ia[b]				
2. *Different volumes maintained at the same T; compare amount HE required to maintain T.*		√*				√*						
3. Different volumes with the same ΔT; compare the amount time for ΔT, infer a[illegible] amount of HE transferred.	√			√	√	√	√		√			
4. *Different volumes with the same ΔT; compare amount of HE transferred.*			√*	√*	√*			√*		√*[c]		
5. *Different volumes w/ same amount of HE added; compare ΔT.*[d]		√*	√*		√*		√*	√*				
6. *Different substances w/ same amount of HE added; compare ΔT.*[d]			√*						√*	√*		
7. Same volume w/different amounts of HE added; compare ΔT.		√					√	√				
8. *Calorimetry (calculate HE).*	√*	√*									√*	√*
9. *Phase change; note ΔHE but no ΔT.*				√*				√*				
Textbook Readings			√	√					√	√		
Discussion	√				√	√	√					
Other			1				1[e]		1		uns.*	uns.*
TOTAL number of strategies.	3	4	6	5	4	3	6	5	4	3	≥2	≥2
TOTAL number of strategies emphasizing the distinction between HE and T.	1	3	4	3	2	1	1	3	1	2	≥2	≥2

Key:

*	The activity described emphasized the distinction between HE and T.	ΔT	Change in T.
√	The teacher described an activity which matched the activity type.	ΔHE	Change in HE.
ia	Activity described by the teacher used an incorrect variable for comparison in the situation.	HE	Heat energy.
uns.	Number of activities was unspecified but several were implied; they may or may not have been of a different types.	T	Temperature.
		w/	With.

[a] The strategies under the "Activities" heading are laboratory activities. Each activity listed is identified in terms of its essential features, i.e., the independent, dependent, and controlled variables. Those activities which emphasize the distinction between heat energy and temperature are italicized, and in the columns showing the teacher data, they are additionally marked with an asterisk.

[b] Activity described by teacher was intended as a demonstration.

[c] The teacher described two very different activities fitting this context. One of the activities would ordinarily have fit the strategy immediately preceding this in the list; however, she included the element that heat energy would be calculated, and that matched this strategy instead.

[d] This activity type typically requires the heat pulser peripheral.

[e] Not enough information was provided to determine whether the named activity emphasized the distinction between heat energy and temperature.

Table 8

Teachers' Content Frameworks for Teaching About Heat Energy and Temperature

		MICROSCOPIC	MACROSCOPIC			
	INTV.	Molecular Framework	Factor Framework	Energy Framework	Transfer Framework	OTHER
Ms. Baxter	F	√	√			
	S	√		√		
Ms. Carlson	F	√			√	
	S				√	
Ms. Gentry	F			√	√	T gives an idea of the HE in a system.
	S	√		√		
Ms. Lowry	F		√	√		
	S	√	√			
Ms. Mason	F		√			
	S					HE is energy; T tells how much.
Mr. Roberts	F		√		√	
	S		√		√	

Table 9

Teachers' Heat Energy and Temperature Activities[a]

ACTIVITIES[b]	Baxter	Carlson	Gentry	Lowry	Mason	Roberts
	TEACHERS					
A Question of Touch	√	√	√	√	√	√
Warm Glove Mystery	√					
Chill Out	√					√
Home on the Range	√					
Isn't it Gradient	√				√	√
Hot Chocolate	√					
Slalom	√	√				
Stirring Things Up	√	√	√		√	√
Keep it Hot	√	√				
Heating Things Up[c]	√*	√*	√*	√*	√*	
Mass & Heat Addition[c]			√*	√*		
Thermostat			√*	√*		
Volume and Cooling		√*				
Heat Transfer - Conduction	√					√
Relative Humidity	√ (m)					
Radiation Lab	√					√
HE and Different Substances					√* (w/GT)	
Greenhouse Effect	√					
Peanut Lab	√*			√* (qual.)		
Boiling Point		√* (m)	√*	√*	√*	
Electrical Energy to HE				√		
Mechanical Energy to HE			√*	√*	√*	
OTHER	3 (1*)	1*				1
TOTAL	18	8	7	8	7	7
Total of activities emphasizing the distinction between HE & T	3	4	5	6	3/4	0

Key:

*	Designates an activity which emphasized the distinction between HE and temperature.
√ (m)	Designates that the activity was conducted manually instead of as an MBL.
√ (w/GT)	Designates an activity used only with gifted and talented students.
HE	Heat energy.
qual.	Designates the approach to the activity was qualitative instead of quantitative as is typical

[a] Unless otherwise noted, the activities were carried out as MBL activities.

[b] Activities which emphasize the distinction between heat energy and temperature are designated in italics, and in the columns showing the teacher data, they are additionally marked with an asterisk.

[c] This activity requires the heat pulser peripheral.